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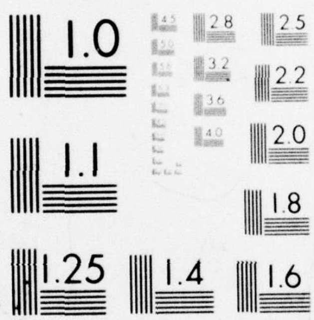

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TECHNIQUES FOR MAKING GAP-COUPLED ACOUSTOELECTRIC DEVICES*

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ABSTRACT The techniques recently developed for fabricating, inspecting, assembling and packaging silicon-on-$LiNbO_3$ acoustoelectric devices, such as amplifiers, convolvers and memory correlators, will be presented. This will include: description of the lithographic and ion beam etching techniques employed in making the spacer posts, demonstration of the techniques used for eliminating dust and achieving uniform gaps, inspection methods, and several examples of packages. Experience to date indicates that the techniques for making gap-coupled structures are reliable, and lend themselves to widespread application.

In a gap-coupled acoustoelectric device it is important that the separation between the semiconductor and the piezoelectric substrate be uniform over the interaction length. The separation or gap is typically 500 to 3000 Å, and must be held constant to about 100 Å. In the past, it was widely believed that these requirements were too difficult to meet in practical device fabrication, and out-of-the-question for large scale manufacture. This belief, in turn, led to a general preference for monolithic devices and the use of deposited semiconductor thin films. Indeed, the separated medium acoustoelectric device, insofar as it involves a non-planar technology, runs counter to the general trend in device fabrication over the last decade. The separated medium device, however, permits one to independently choose the optimum semiconductor and the optimum piezoelectric, and this advantage far outweighs the disadvantage of developing special non-planar fabrication and assembly techniques. In this paper, we describe the techniques that have been developed for making gap-coupled devices. These appear to be reliable and adaptable to widespread application.

Posts

Figure 1 depicts a cross-section through an assembled silicon-on-$LiNbO_3$ gap-coupled device. The semiconductor is held away from the $LiNbO_3$ by means of posts which extend up from, and are part of, the $LiNbO_3$ surface[1]. The semiconductor is pressed down on the posts by means of a soft plastic pillow. The function of the pillow is to take out the curvature of the silicon, and insure that the silicon contacts the posts over the entire interaction length, while at the same time minimizing any variation in pressure. The pillow also serves to prevent the silicon from sliding relative to the $LiNbO_3$ substrate. The pressure that the pillow applies is not known in absolute terms. However, the distance that the silicon is pressed into the pillow is directly measured and this is, in effect, an operational calibration. From experience, one can determine the minimum amount of compression needed to achieve a uniform gap and mechanical stability, the range of compression that can be safely used, and the amount of compression that causes fracture of the posts.

In the acoustoelectric amplifier developed by Ralston [2], the semiconductor is thin film silicon on a 4 cm diameter sapphire wafer. The silicon is pressed onto the $LiNbO_3$ by means of air pressure applied behind the sapphire wafer as illustrated in Figure 2. The air pressure performs the same function as the plastic pillow. Pressure uniformity is a natural consequence, and absolute calibration is possible. Pressures up to one atmosphere can be safely applied without damaging the posts. Figure 3 is a photograph of the amplifier package.

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The posts are typically 3.5 μm square, located on approximately 200 μm centers. Their actual positions are randomized in order to avoid cooperative reflection effects. At frequencies up to 300 MHz, the effect of the posts on the propagation of surface elastic waves is not easily measured, and is probably less than 1 dB attenuation over a 3 cm path length. The shape and size of the posts is very important, and to achieve consistency considerable care must be exercised in the photolithography and ion beam etching.

Photolithography

The posts are produced by the following steps:

1. The $LiNbO_3$ surface is coated with about 1 μm thickness of AZ1350 J. photoresist.

2. This is then exposed except for a region somewhat larger than the desired interaction region, and the resist is developed.

3. The post pattern is exposed and developed.

4. The entire substrate is ion beam etched, thereby leaving posts in relief.

In order to produce well defined posts of correct cross section, the photoresist must be exposed with the photomask in intimate contact. If this is not done, and there is a finite air gap, the diffraction which occurs in this gap will very quickly destroy the pattern. This will in fact occur more readily for a post pattern than for a parallel grating geometry pattern. Moreover, because the post pattern mask is transparent in 99.98% of its area, backscattering of light is an important consideration and can lead to exposure difficulties. We have found that conformable photomask lithography [3-6] using the instrumentation described in [6] is well suited to post pattern exposure. The platform on which the crystal is mounted during exposure is blackened in order to eliminate the light backscatter problem.

Ion beam etching of the post pattern is straightforward. Techniques have been described elsewhere [4,7,8]. Ion beam etching in argon alters the stoichiometry of the $LiNbO_3$ within about 100 Å of the surface. This material is removed in an HF: HNO_3 acid etch. Alternatively, ion beam etching in a partial pressure of oxygen can be used[4].

The processes for preparing the semiconductor components of a gap coupled device vary greatly from one device to the next, and it is not possible to describe these here. The most common configuration has been a thin strip of silicon about 4 cm long, 1 mm wide and 1/4 mm thick, with wires bonded to the back side. It is helpful if the front surface of the silicon is covered by a oxide to protect it from damage during bonding handling, etc. This oxide can be removed just prior to assembly.

Cleaning and Assembly

During the bonding and mounting of the delay line, a considerable amount of contamination, primarily dust particles, unavoidably collects on its surface. These will, of course, prevent one from achieving a uniform gap. Conventional substrate washing and ultrasonic cleaning procedures are ineffective once a device is mounted in its package. However, contaminants need be removed only from the region that will face the semiconductor. For such selective cleanup we found that contaminants are very effectively removed by capturing them in a plastic coating, and then peeling the coating after it has dried and hardened.

Specifically, the surface is coated with collodian (in 24% alcohol), while at the same time rubbing the surface with a swab to insure a thorough wetting by the collodian. A second layer of collodian is then put on, followed by a strip of fine silk-screen cloth (33 lines per cm) followed by two or three more layers of collodian. Once the collodian is dry, it can be removed by peeling back the silk cloth. In many cases, the peeling back occurs spontaneously. It appears that this cleaning procedure thoroughly removes all traces of contaminants that would otherwise interfere with a uniform gap.

The semiconductor slab is mounted on the plastic pillow shown in Fig. 1. If there is a protective oxide on the front surface of the slab this is removed just prior to mounting. A clean optical flat is then pressed against the mounted slab, and the contact region inspected for the presence of any dust particles or chips along the edges of the slab. If such are present, they are readily removed by the plastic coating method described above. If the slab is very narrow (~1 mm) it is usually convenient to omit the silk cloth, as this tends to cause plastic to also coat the sidewalls and underside of the slab. Cleaning by the plastic coating method is particularly useful on silicon slabs that have arrays of Schottky diodes[9,10] or other structures of their surfaces. The processing and handling involved in producing such structures, and especially the cutting into narrow slabs, generally leaves a large amount of contamination on the surface, and this contamination tends to cling to such non-smooth surfaces. The plastic tends to follow the surface relief structure thereby encapsulating the dust particles. The technique of plastic coating and peeling has been used for many years to cast replicas of surfaces, and such replicas have been shown by electron microscopy to replicate surface features of the order of 50 Å in size.

Inspection of the semiconductor slab by pressing against an optical flat and observing the interference fringes affords one an opportunity to reject slabs if they have extreme curvature, are twisted, or have surface defects. On the semiconductor mounting fixtures used in this laboratory there are reference surfaces against which the optical flat can be pressed. This requires some compression of the RTV pillow. The amount of compression can be directly measured by means of a dial indicator. This together with the known dimensions of the package and thickness of the delay line permits one to calculate the amount of compression there will be in the assembled gap-coupled acoustoelectric device. Such precise measurements are essential in order to achieve a stable gap without damage to the posts.

Once the two parts of the acoustoelectric device are cleaned and inspected, they are aligned and assembled in a clean bench environment. This part of the procedure is straightforward.

In the past, the major difficulty with gap coupled devices has always been dust particles. If they are present in the interaction region, a uniform gap cannot be obtained, and efforts to assemble a device under such circumstances usually result in damage to the component parts and less than uniform performance. On the other hand, if dust particles are removed from the interaction region, if the posts are all present, and if the two parts are free of extreme curvature, it is difficult to fail to achieve a uniform gap.

Acknowledgements

In these efforts to develop reliable techniques for making gap-coupled acoustoelectric devices R. Slattery provided the essential technical assistance. E. Stern contributed the idea of the posts.

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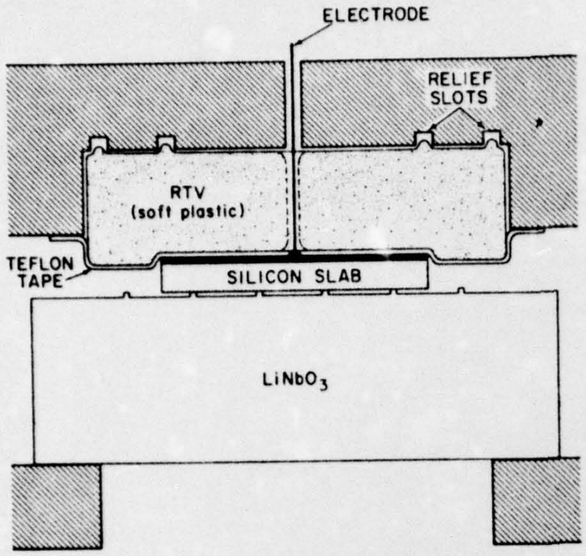

Fig. 1 Schematic cross-section through an assembled silicon-on-$LiNbO_3$ gap-coupled acoustoelectric device. The silicon slab is held away from the $LiNbO_3$ by means of posts which extend up from the $LiNbO_3$ surface. A soft plastic pillow presses the silicon onto the posts to achieve gap uniformity.

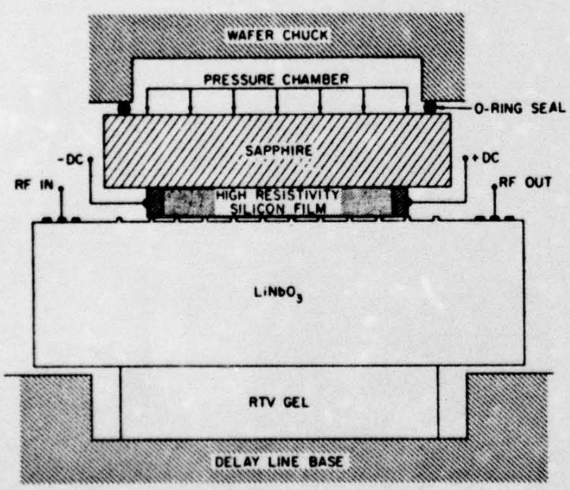

Fig. 2 Schematic lengthwise cross-section through the acoustoelectric amplifier developed by Ralston[2]. The silicon-to-$LiNbO_3$ gap is maintained by means of posts extending up from the $LiNbO_3$ surface. Air pressure is applied to press the silicon onto the posts.

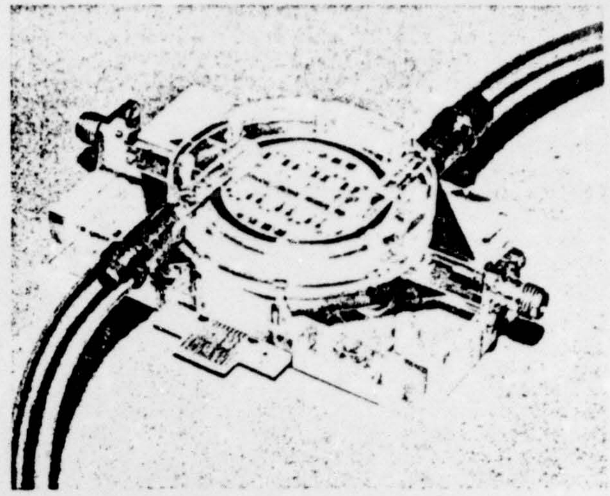

Fig. 3 Photograph of the acoustoelectric amplifier structure illustrated schematically in Fig. 2.

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The techniques recently developed for fabricating, inspecting, assembling and packaging silicon-on-$LiNbO_3$ acoustoelectric devices, such as amplifiers, convolvers and memory correlators, will be presented. This will include: description of the lithographic and ion beam etching techniques employed in making the spacer posts, demonstration of the techniques used for eliminating dust and achieving uniform gaps, inspection methods, and several examples of packages. Experience to date indicates that the techniques for making gap-coupled structures are reliable, and lend themselves to widespread application.

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